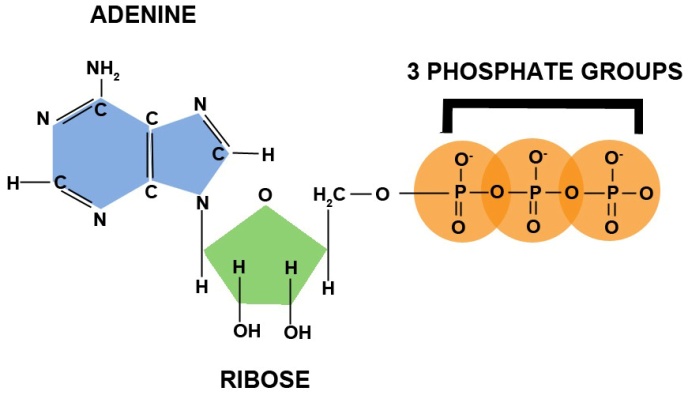
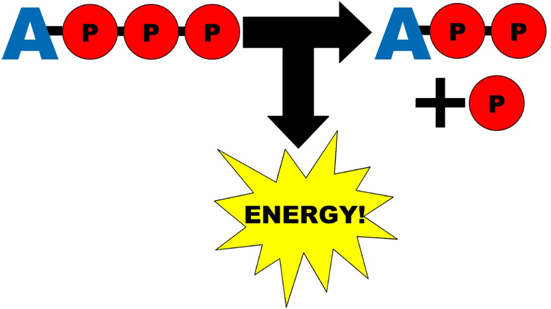
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**Unit 4, Part 1 Notes: The Basics of Energy and Cellular Respiration**

Ms. Ottolini, PreAP Biology

**Overview of Cellular Respiration:**

Cellular Respiration is the process by which living organisms break down glucose (a simple sugar molecule). The energy released from the bonds in the sugar molecule is used to create a more usable energy molecule, ATP. All living organisms convert glucose into ATP because they can easily harvest energy from ATP when they need it to fuel cellular processes (ex: active transport of substances across the cell membrane). The full name for ATP is adenosine triphosphate. The first part of the molecule, adenosine, contains adenine—a nitrogen base found in both DNA and RNA—and ribose—a monosaccharide (sugar) found in RNA only. Adenosine is bonded to three phosphate groups. The bonds between each phosphate group store a lot of energy. To release energy from an ATP molecule in order to fuel a particular cell process, all you need to do is break the bond between the last two phosphate groups.

To create ATP, organisms must have a source of glucose. Autotrophs are organisms that can make their own glucose / food. (Note: autotroph literally means “self feeder.”) Some autotrophs make glucose using a process called photosynthesis (using the energy from sunlight to rearrange the atoms in carbon dioxide and water to make glucose). Examples of photosynthetic autotrophs include plants, algae, and some types of bacteria. Some autotrophs use energy from simple chemicals (ex: hydrogen gas, hydrogen sulfide, or methane) instead of sunlight to rearrange CO2 and H2O to make glucose. These autotrophs are called chemoautotrophs (Note: “chemo” stands for “chemical”). Chemoautotrophs are typically bacteria.

Heterotrophs, in contrast, are organisms that cannot make their own food and have to obtain glucose by eating other organisms. Animals and fungi are examples of multicellular heterotrophs. Animals digest their food inside their bodies, whereas fungi secrete (release) enzymes to break down their food source outside their bodies and absorb the nutrients using finger-like projections called hyphae. The fungus that causes athlete’s foot actually secretes enzymes to digest the outer layer of your foot skin. GROSS!!! Single-celled (unicellular) organisms can also be heterotrophic. Certain types of bacteria are heterotrophs and certain protists (ex: amoebas) are heterotrophs are as well.

No matter how organisms obtain glucose, they must convert the energy in glucose to the energy in ATP through cellular respiration. Many organisms use aerobic respiration, a process that requires oxygen. The overall equation for aerobic respiration is given below, with the reactants (starting molecules) on the left side of the arrow and the products (ending molecules) on the right side of the arrow.

***Equation with Chemical Symbols:***

C6H12O6 + O2 🡪 ATP + CO2 + H2O

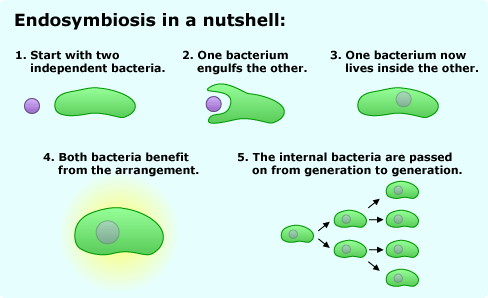
***Equation with Words:***

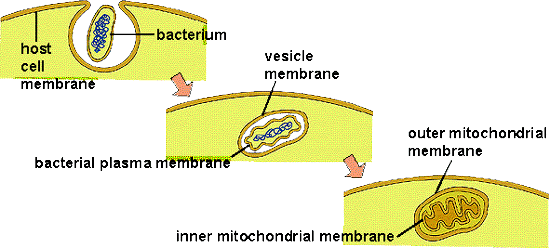
Glucose + Oxygen 🡪 Adenosine Triphosphate + Carbon Dioxide + Water

Some organisms do not have oxygen in their environment and therefore cannot use aerobic respiration. They use a different form of respiration called anaerobic respiration, which literally means “respiration without oxygen.” An alternate name for anaerobic respiration is fermentation. There are two types of fermentation depending on the waste products created, and we will discuss these types of fermentation later.

**Where does Cellular Respiration Occur?**

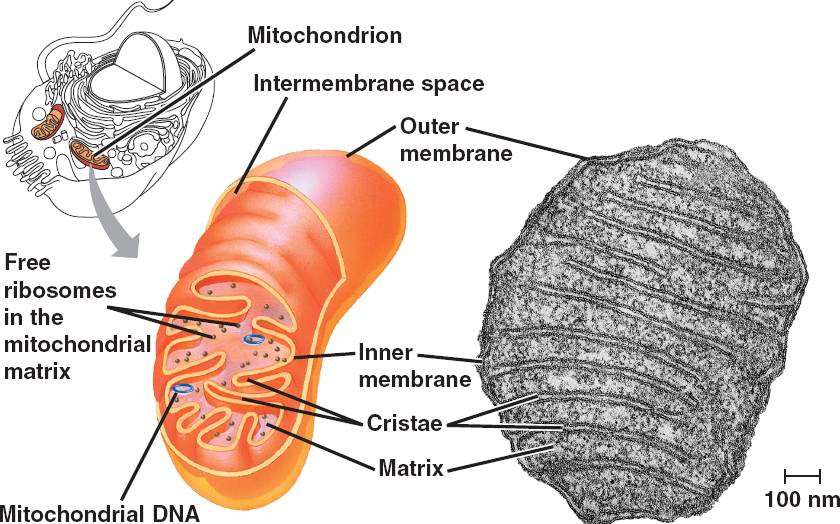
Cellular respiration occurs in the mitochondria of eukaryotic cells. Prokaryotic cells (ex: bacteria) do not have mitochondria, but they can perform cellular respiration in their cell membranes. Scientists actually believe that the first eukaryotic cells with true organelles were created when a large prokaryotic cell swallowed a small prokaryotic cell that was really good at cellular respiration. That smaller cell provided ATP for the larger cell, and the larger cell provided the smaller cell with glucose and a nice place to live. In other words, they had a symbiotic (mutually beneficial) relationship. Eventually, the smaller cell lost the ability to live on its own outside the larger cell and became an organelle (more specifically, a mitochondrion). The process of the larger prokaryotic cell “swallowing” the smaller prokaryotic cell is called “endosymbiosis.” The “endo” part of the name stands for endocytosis—a process by which cells can engulf / swallow large amounts of material by wrapping their membrane around these materials (ex: the smaller cell). The “symbiosis” part of the name describes the relationship the larger cell forms with the smaller, swallowed cell.





Evidence to suggest that mitochondria were once free-living prokaryotic cells includes the fact that they have their own DNA and ribosomes. They also have a double membrane—one from their former life as free-living cells and one that they received when the large cell wrapped its membrane around them during the “swallowing” process.

Mitochondria have an outer and inner membrane. The inner membrane has folds called cristae that maximize the amount of inner membrane that can fit inside the mitochondrion. The inner membrane is the location of the last step of cellular respiration—the electron transport chain—which generates the most ATP. If there is more inner membrane (i.e. more cristae), there can be more electron transport chains, and more ATP can be created. The space between the two membranes is called the intermembrane space, and the inside of the mitochondrion (inside both membranes) is called the mitochondrial matrix (or just the matrix).



**What are the Steps of Cellular Respiration?**

The first step of cellular respiration is called glycolysis. This step does not occur in the mitochondrion at all… it actually occurs in the cytoplasm of the cell! During glycolysis, glucose is broken down into two smaller molecules called pyruvate. In this process, two molecules of ATP are made and high-energy electrons are taken from glucose and added to NADH, an electron carrier. NADH is like a “piggy bank.” It holds onto high-energy electrons from glucose and carries them to the last step of cellular respiration (the electron transport chain). In the electron transport chain, the “piggy bank” can be broken open to release the high energy electrons. The energy from these electrons can be used to create more ATP.

The second step of cellular respiration is called the Krebs Cycle. This step occurs in the matrix of the mitochondrion, after pyruvate has diffused through both mitochondrial membranes. During the Krebs cycle, pyruvate is further broken down into carbon dioxide. In this process, two more molecules of ATP are made, but the main goal is to create MANY piggy banks (NADH) using high-energy electrons taken from pyruvate. These NADH molecules are then sent to the electron transport chain.

The electron transport chain is the third step of cellular respiration in which the most ATP is made (32-34 ATP for each glucose molecule broken down during cellular respiration). This process occurs in the cristae / folds of the inner mitochondrial membrane. During this process, the following steps take place:

1. The piggy banks (NADH) molecules are broken and high-energy electrons are released.
2. These high-energy electrons are passed from membrane protein to membrane protein.
3. At each membrane protein some energy is taken from the electrons, and this energy is used to pump H+ (hydrogen ions) from the matrix to the intermembrane space.
4. The last molecule to receive the electrons is oxygen gas (O2). Oxygen gas combines with the electrons and H+ to form H2O, one of the products of cellular respiration.
5. H+ builds up in the intermembrane space. This creates a concentration gradient across the inner mitochondrial membrane with a high concentration of H+ in the intermembrane space and a low concentration of H+ in the matrix. H+ “wants” to flow down its concentration gradient from the intermembrane space across the inner mitochondrial membrane to the matrix.
6. The only way that H+ can diffuse across the membrane is through ATP synthase, another membrane protein. As H+ ions flow through ATP synthase, the protein turns, and this turning motion causes ADP (adenosine diphosphate… di for two phosphate groups) and a single phosphate group (P) to squish together and create ATP.

**Diagramming the Electron Transport Chain (draw with Ms. Ottolini)**

**How is Anaerobic Respiration (aka Fermentation) different from Aerobic Respiration?**

Anaerobic respiration only involves glycolysis and a couple other small reactions. The Krebs cycle and the electron transport chain do not occur during anaerobic respiration.

There are two main types of anaerobic respiration—alcoholic fermentation and lactic acid fermentation.

Yeasts and some bacteria use alcoholic fermentation, forming ethyl alcohol (aka ethanol) and carbon dioxide as wastes in the process of making ATP. Alcoholic fermentation by unicellular fungi called yeast causes bread dough to rise. When yeast in the dough runs out of oxygen, it begins to ferment, giving off bubbles of carbon dioxide which form the air spaces you see in a slice of bread. The small amount of alcohol produced in the dough evaporates when the bread is baked. Alcoholic fermentation by yeast is also used in the process of making beer and wine.

Lactic acid fermentation occurs in your muscle cells during rapid exercise when the body cannot supply enough oxygen to the tissues. Without enough oxygen, the body is not able to produce all of the ATP that is required. (Remember, glycolysis is the only step of cellular respiration used in anaerobic respiration, and this only makes small amounts of ATP.) When you exercise vigorously by running, swimming, or riding a bicycle as fast as you can, the large muscles of your arms and legs quickly run out of oxygen. Your muscle cells “decide” that a small amount of ATP is better than none, and they begin to create this ATP by lactic acid fermentation. The buildup of lactic acid (a waste product of the process) causes a painful, burning sensation. This is why muscles may feel sore after only a few seconds of intense activity.

**Questions to Accompany the Notes**

***Directions:*** *Answer each question below thoroughly and accurately. Use complete sentences.*

1. Why do organisms use ATP rather than glucose to power reactions in the body (ex: active transport of substances across cell membranes)?
2. Compare and contrast autotrophs and heterotrophs. How do they obtain glucose? Do they have chloroplasts, mitochondria, or both?
3. Explain the difference between a photoautotroph and a chemoautotroph.
4. How do scientists believe eukaryotic cells “acquired” mitochondria? Describe the process by which mitochondria went from being free-living cells to organelles within a eukaryotic cell.
5. Identify the locations of the three steps of cellular respiration (i.e. glycolysis, the Krebs cycle, and the electron transport chain) in the cell and mitochondrion.
6. What is the overall goal of glycolysis?
7. What is the function of NADH? Why do we call it a “piggy bank”?
8. What is the overall goal of the Krebs cycle?
9. What is the overall goal of the electron transport chain?
10. How is the concentration gradient of H+ used to make ATP? (Hint: Describe what happens when H+ flows through the ATP synthase protein located in the inner mitochondrial membrane).
11. How is anaerobic respiration (aka fermentation) different from aerobic respiration? Which step(s) of aerobic respiration (i.e. glycolysis, the Krebs cycle, the electron transport chain) are used during anaerobic respiration?
12. Compare / contrast lactic acid fermentation and alcoholic fermentation. What are their waste products, and what types of organisms use these forms of fermentation?